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EXPLOSIVE TESTS FOR ESTABLISHING HAZARD CLASSIFICATION FOR M1SP PROPELLANT IN AUTOMATED SINGLE-BASE FINISHING OPERATIONS

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Adequacy of a prototype propellant storage hopper was established for venting burning reaction gases to preclude an explosive reaction in the air-dry operation of the automated single-base line (ASBL). Four hundred and fifty pounds of M1SP propellant (for 105 mm ammunition) did not transit from burning to an explosion when bottom flame initiated in a specially designed hopper incorporating pressure-relief venting. Implementation of this hopper design will reduce an assessed Class 7 explosive hazard to a Class 2 burning hazard in ASBL finishing operations.

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20. Abstract (Contd)

The ratio of propellant surface to hopper vent area was determined which will permit venting of burning gases and, in turn, preclude an explosive reaction in manufacturing and storage vessels. Also the susceptibility of M1SP propellant to transit from burning to an explosion was established in steel confinement in test diameters up to 18 inches.

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INTRODUCTION

Objective

The objectives of this study were to (1) design and test the venting adequacy of a proposed propellant storage hopper for precluding explosive reactions when M1SP propellant (for 105 mm ammunition) is flame initiated, (2) establish the hazard classification for 450 pounds of M1SP propellant in these hoppers for automated single-base finishing operations (ASBL) air-dry operations, and (3) define the flame-initiated explosive characteristics for M1SP propellant confined in steel.

Background

The manufacturing and support facilities within the ASBL being constructed at Radford Army Ammunition Plant (RAAP) are separated for propellant quantities posing only a Class 2 burning hazard. A safety problem evolved when the mission of the ASBL was changed to include M1SP propellant manufacturing capability. This change resulted in the M1SP propellant-bed depth exceeding the maximum limit of 18 inches (AMCR 385-229) in the air dry modular-discharge hoppers. Exceeding the 18-inch critical bed-depth requirement in this processing phase changed the defined in-process hazard classification for M1SP from a Class 2 burning hazard to a Class 7 explosive hazard. Without design changes, a Class 7 in-process hazard classification would curtail the manufacture of the M1SP formulation within the present ASBL design. Changes in modes of operation to eliminate the potential explosive hazard or to provide Class 7 protective barricading would require extensive modifications to existing structures and equipment as well as new construction, and would cause extended delay in project completion.

Process review had shown that the present mode of operation could not be changed easily without extensive modifications to maintain an M1SP propellant height below the 18-inch critical bed depth in the discharge hopper. Therefore, a hopper design incorporating pressure-relief venting was introduced, together with a confirmatory prototype-hopper test program. Tests were conducted to ensure that the proposed venting concept would prevent an explosive reaction in the event flame initiation occurred for 450 pounds of M1SP propellant in the hopper.

In addition, critical height-to-explosion tests were performed to (1) define the flame-initiated explosive characteristics for M1SP in large test diameters, and (2) determine if a correlation exists between critical height-to-diameter and propellant bed depths in this hopper design.

This test program was conducted by the Hazards Analysis Group, RAAP, and performed with the assistance of personnel from and use of Hercules, Incorporated, test facilities at Cumberland, Maryland, and Frackville, Pennsylvania, under the technical cognizance and funding of Picatinny Arsenal.

DISCUSSION

Hopper Design

Heretofore, technology was not available to design pressure-relief panels for venting burning propellant gases to preclude destructive pressures, or propellant transition from burning to explosive reactions, in finely packed beds. In the absence of such information as venting requirements, and relief-panel location, size, mass, and materials of construction, the approach (taken in the design of the ASBL air-dry hopper) was to introduce maximum venting without jeopardizing the structural integrity of the equipment itself. The prototype hopper shown in Figure 1 was designed with an effective pressure-relief vent area of 9.69 ft^2. Other design information for the hopper and individual vent-panel sizes, locations, and material of construction are identified in Figures 2 and 7. Hoppers were fabricated by the Rexnord Company, Louisville, Kentucky.

The hopper top opening has an apparent 9-ft^2 area; however, the effective area for pressure-relief purposes is 2.25 ft^2, which is the cross-sectional area limited by an inner, upper baffle (Fig 3a and Table 1). This effective area must be used because the 450-pound propellant level is below the upper baffle, and gases escaping are restricted by the vent area allowed by this baffle opening. A 0.35 ft^2 of venting is also provided by the 8-in.-diameter bottom discharge port. To maximize venting in the hopper design, additional venting in the form of 16 side-vent panels was incorporated and increased the effective vent area to 9.69 ft^2 (Fig 1 and Table 1).

Although the need did not arise, an alternate hopper design provided for four additional pressure-relief panels in the hopper-bottom conical section. This design feature could add 3.42 ft^2 of additional venting if needed.

The internal baffling served two purposes; it prevented having a propellant column against the side vent panel and aided in directing burning gases and propellant from the hopper interior.

The side vent lids were made of neoprene rubber with a steel plate bonded on the outside to enhance the stability and sealing capability of the neoprene. The hinges of the lids were an integral part of the neoprene to eliminate any possibility of a malfunction of a mechanical joint (Fig 3b).

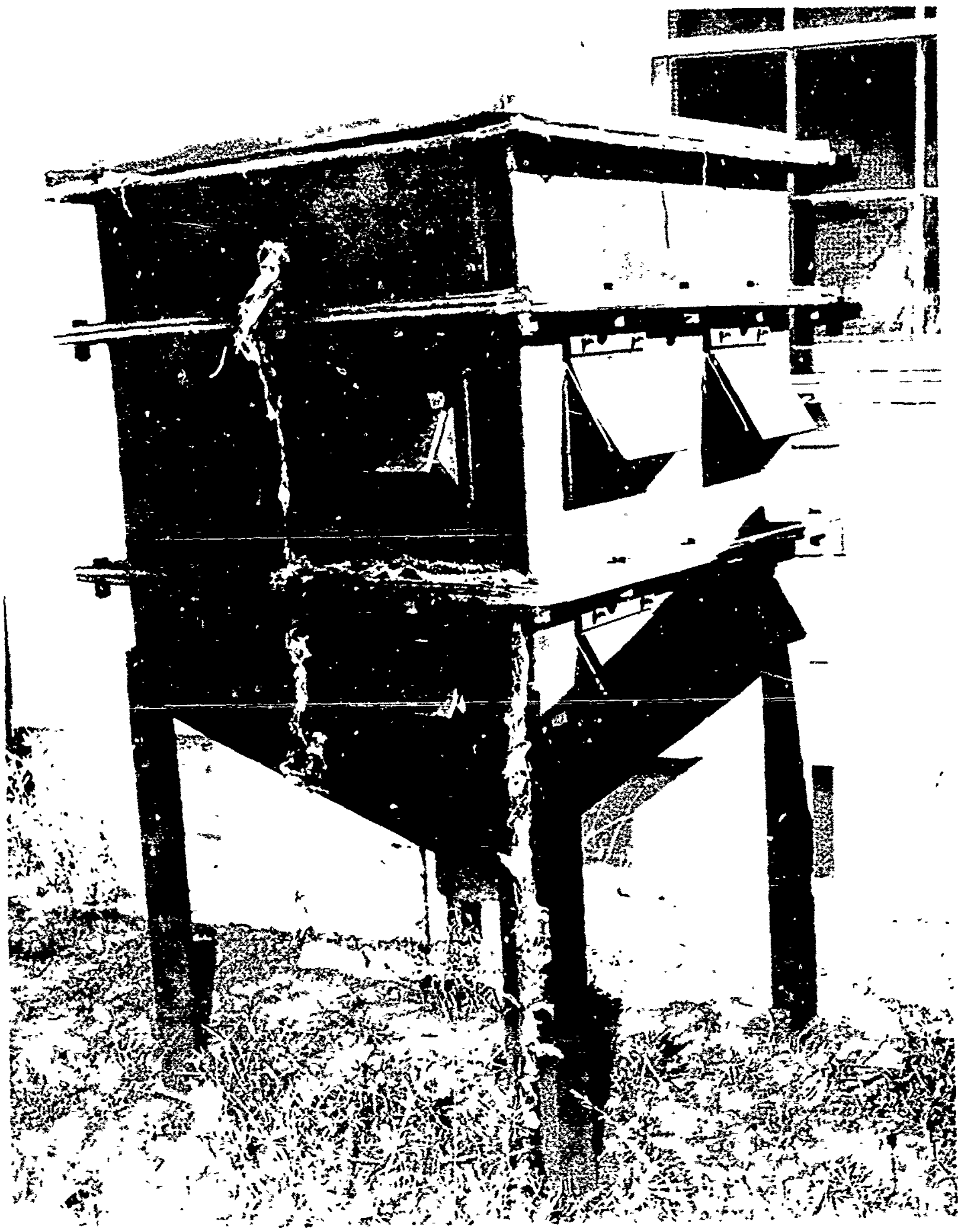


Fig 1 Prototype hopper with pressure-relief vent panels
(after ten test trials)

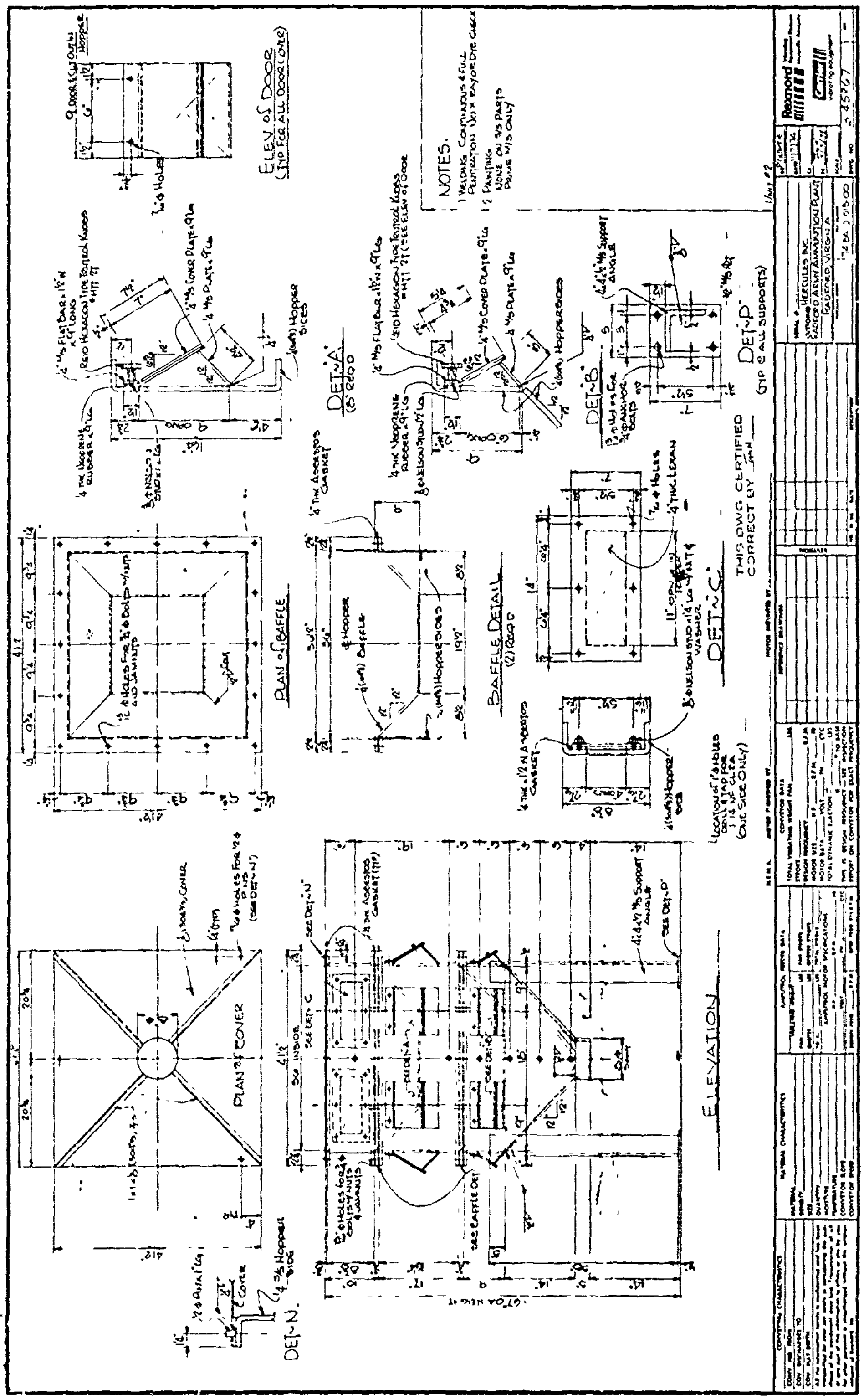


Fig 2 Final design of vented hopper for ASBL

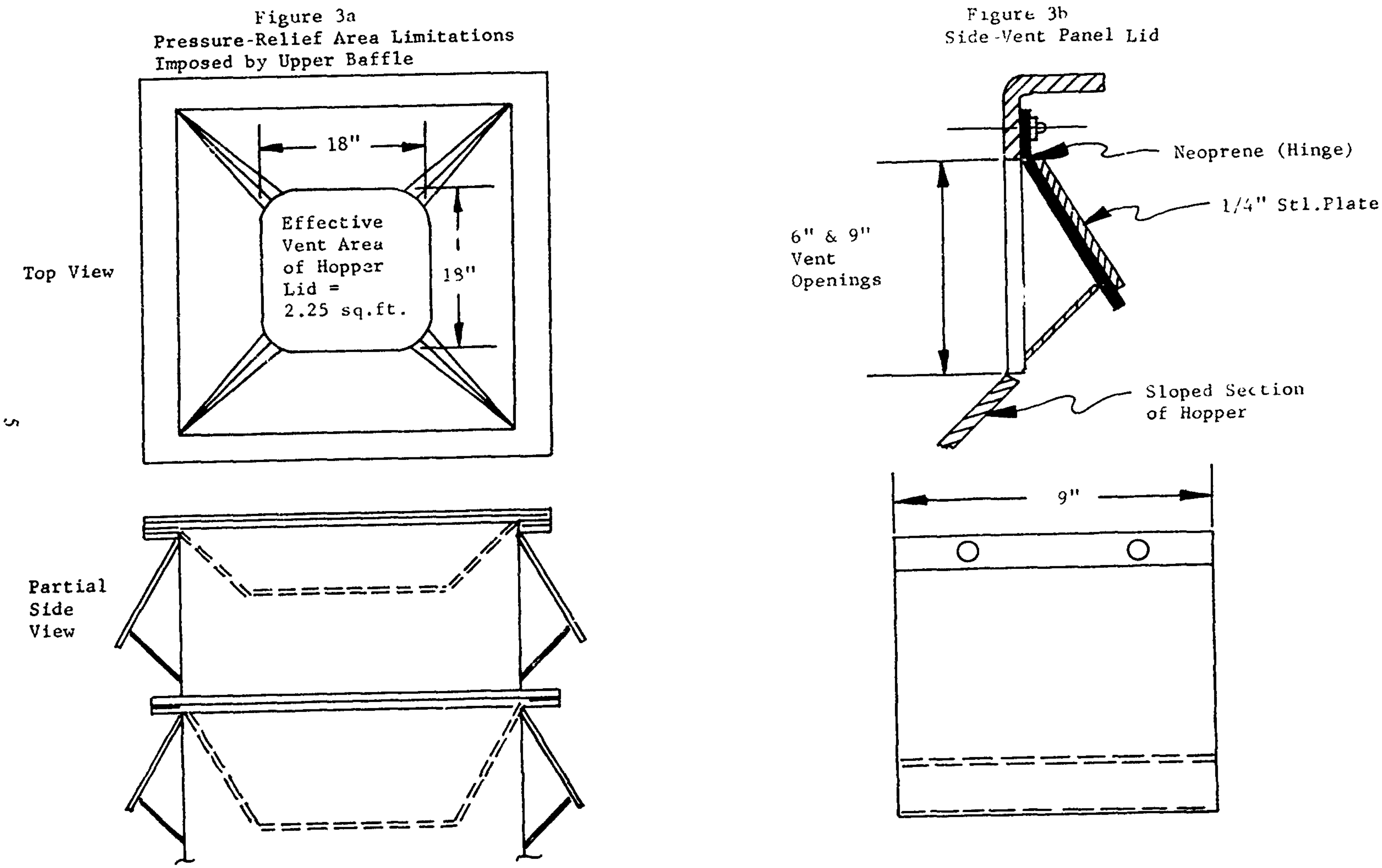
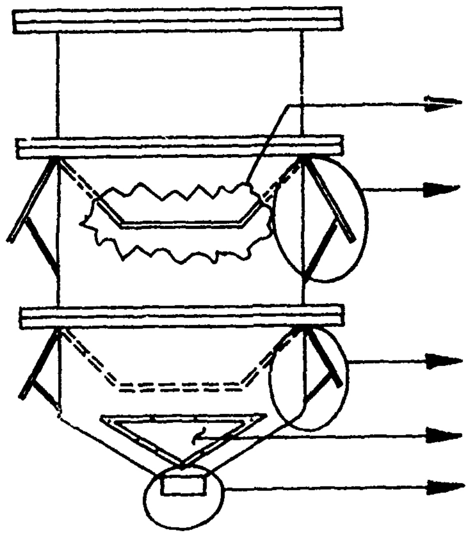


Fig 3 Hopper design particulars

Table 1

Calculated propellant surface-to-hopper vent area ratio

Hopper Vent Area



	Effective Vent Area (ft^2)
Top Baffle Opening	2.25
8 Top Side Vents ($8 \times 0.532\ ft^2$)	4.26
8 bottom Side Vents ($8 \times 0.354\ ft^2$)	2.83
Optional ($4 \times 0.965 = 3.86\ ft^2$)	--
Discharge Opening	0.35
	$9.69\ ft^2$

Propellant Surface Area (M1SP f/105mm) 1/

Granule Length = 0.20 in.; Diameter = 0.045 in; web = 0.013 in.

Perf. ID = 0.0202 in.; Density = 1.526 gm/cm^3

Surface Area/pound = 21.575 ft^2/lb

$$\text{Ratio} \quad \frac{\text{Propellant Surface Area}}{\text{Hopper Vent Area}} = \frac{300\ lbs \times 21.575\ ft^2/lb\ ^{2/}}{9.69\ ft^2}$$

$$= 668$$

1/ Nominal values

2/ The surface area for approximately 1/3 of unburned propellant (150 pounds) estimated to have been expelled from the hopper did not contribute to gas generation within the hopper, thus was subtracted from total propellant quantity present.

Since the AMCR 385-229 requirement restricted propellant height to 18 inches, the first module consisting of eight vent panels was located 17 inches above the hopper discharge outlet. The second module of eight vents was positioned approximately 17 inches above the first module to be consistent with the AMCR 385-229 criteria.

Test Design

The discharge hopper design depicted on Rexnord Dwg. No. 3-45867 (Fig 2) was evaluated with up to 450 pounds of M1SP propellant in flame-initiated tests. Initially, tests were performed at reduced propellant quantities of 250 and 350 pounds. This procedure was desirable since it permitted initial checkout and evaluation of instrumentation and hopper components to flame reactions, while providing data for assessing the validity of the restrictive limitation on critical bed depth specified in AMCR 385-229 for this propellant web size. By test design to minimize loss, the bulk of testing was to be performed in a 1/2-inch-thick mild steel (heavier wall) hopper rather than the 1/4-inch-thick stainless steel prototype hopper. It was believed that the heavier-walled hopper was necessary to assure dimensional stability when subjected to repeated tests. However, this hopper was phased out after the third test trial because visual examination revealed that virtually no damage (erosion, warpage, etc.) was occurring to the hopper and vent assemblies. Also, it was highly desirable to perform as many confirmatory trials as possible in the prototype design.

Provisions were incorporated in the hopper design to obtain pressure/time data for analysis and correlation with related internal pressure magnitudes, pressure rate-of-rise at various locations, propellant surface area, and venting. Additionally, to define vent-panel dynamic response to the pressure/time profile of the burning propellant in the test hopper, suitable accelerometers were mounted on the exterior of the vent panels.

All test trials were monitored by high-speed and real-time photographic coverage from different locations to fully observe the functioning of all venting panels during the test.

Prototype Tests and Analyses

Full-Scale Tests

Results of full-scale hopper tests are presented in Table 2. The data revealed that 450 pounds of M1SP propellant resulted in burning only when flame was initiated in the specially designed hopper incorporating pressure-relief venting. Thus, the hopper venting functioned, as intended, to prevent internal destructive pressure buildup and/or

Table 2

Large-scale vented hopper tests[a]

	Propellant				Igniter					
Hopper[b]	Type	Physical State	Sample Weight (lb)	Sample Height[c] (in.)	Size	Ingredient	Position	No. Trials	Reaction	Remarks
1/2" Mild Steel	M1SP f/105	Dry Finished Granules	250	19	2 oz	Black Powder	4 inches above hopper discharge opening	1	Orderly burning with huge fireball	No noticeable damage to hopper or neoprene vent panels
			350	23				1		
			450	29				1		
1/4" Stainless Steel	M1SP f/105	Dry Finished Granules	450	29	2 oz	Black Powder	4 inches above hopper discharge opening	10	Orderly burning with huge fireball	No noticeable damage to hopper or neoprene vent panels

a. Tests performed at Frackville, Pennsylvania.

b. See Figure 2 for cross-sectional view of stainless-steel prototype hopper.

c. Propellant height above hopper discharge opening.

propellant transition from burning to an explosive reaction. Pressure-relief venting was provided by 16 side vents plus the effective vent area provided by the hopper top and bottom openings. Ten large-scale tests have been performed in the stainless-steel prototype hopper depicted in Figure 1. High-speed photographic coverage together with visual examination showed that the hopper and neoprene vent panels sustained no noticeable damage such as warping or flame erosion.

A propellant surface-to-hopper vent area ratio of $\approx$660:1 in the full-scale hopper test is more than adequate for preventing violent explosive reaction for 450 pounds of M1SP propellant (Table 1).

On the basis of the successful results achieved in full-scale tests, it is recommended that the specially designed hopper incorporating pressure-relief venting be adopted for use in ASBL finishing operations to eliminate a Class 7 propellant explosive hazard posed by the M1SP formulation.

Film Analysis

High-speed film coverage at 500 and 1,000 frames per second was studied and functioning times for pressure-relief locations established on the basis of panel movement and/or appearance of smoke or flame The reaction times for the lower boot, side vents, and top lid are listed in Table 3. Examination of functioning times shows pressure venting occurs immediately and is first observed at the bottom boot, then at the lower side vents, upper side vents, and the top-lid vent areas. Functioning times in terms of smoke and flame are not constant but are reasonably close as seen by time ranges for each location.

In stainless steel hopper tests with 450 pounds of M1SP, the time from ignition to the first observation of propellant or gases ranged from 24 to 60 milliseconds at the hopper discharge opening (Table 3). A portion of this time was consumed in ignition of the igniter. Flame was observed earliest (approximately 140 milliseconds after ignition) at the hopper discharge opening and at the hopper lid approximately 330 milliseconds after ignition. The total burning time ranged from 9.2 to 12.9 seconds; however, these times include the slow burning of propellant in the simulated discharge conveyor at the hopper bottom.

The overlapping of data only signifies differences in propellant burning characteristics within the bed and passage of smoke and/or flame through the interstices to the observed venting location.

Table 3

Vented hopper film analysis

Trial No.	Hopper Type	Camera Speed Frames (sec)	Propellant Wt (lb)	Time From Ignition (sec)						Total Burning Time (sec)[e]
				Propellant or Gases Observed				Flame Observed		
				Hopper Discharge	Vents		Hopper Lid	Hopper Discharge	Hopper Lid	
					Lower	Upper				
1	MS[a]	500	250	0.028	0.064	0.120	0.122	0.224	0.360	--
2			350	0.026	0.056	0.080	0.140	0.436	0.336	6.8
3			450							
4	S/steel[b]	500	450	0.024	0.084	(c)	0.232	0.398	0.576	10
5				(d)	0.108	0.220	0.200	0.272	0.342	9.2
8				0.036	0.082	(c)	0.180	0.376	0.410	12.9
10				0.060	0.108	(c)	0.032	0.144	0.460	12.9
13				0.032	0.084	(c)	0.260	0.152	0.510	11.2

a Mild steel, 1/2-inch thick.

b Stainless steel (prototype), 1/4-inch thick.

c Could not be observed because smoke and flame engulfed hopper.

d Simulated boot did not rupture until after smoke and flame engulfed hopper.

e Time from ignition to complete burnout of all propellant.

Of particular interest is that hopper venting is accompanied by the initial spewing of unburned propellant granules out of the lower and upper pressure-relief panels. Upon ignition, the propellant bed is apparently fluidized and pressurized with a force sufficient to propel large amounts of unburned propellant granules as far as 25 feet from the hopper. A typical chronological time sequence of this and other events, taken from high-speed film, is depicted pictorially in Figure 4, a through f. As can be seen, unignited propellant granules are expelled from the lower vent panels almost simultaneously with the rupture of the hopper discharge boot. This action is followed by internal pressure forcing propellant out of the hopper top inlet port in the center of the lid. Next the lid is forced off followed by flame exiting out the hopper top opening. This action occurs simultaneously with gases venting out the uppermost side vent panels.

It is obvious from study of high-speed film coverage that unignited propellant spewing from the hopper is contributing to the overall dimension of the resulting fireball sized at 40 to 50 feet in diameter (Fig 4f). The flame emanating from the hopper eventually extends upward to approximately 150 feet in height and terminates into a mushroom-shaped fireball approximately 100 feet in diameter. However, it appears at this time that the fireball created must be contained in order to minimize facility damage. Some proposed remedies to this problem are the use of flame-arresting screens located around the hopper, fire walls, or a system to direct unignited or burning propellant granules funneled out of the pressure-relief vent ports into a water bath or moat. The feasibility and suitability of these methods needs to be explored.

Although not studied in detail, it appears that application of Primac-operated deluge systems would not aid in preventing growth or containment of the ensuing fireball.

Pressure Versus Time

Piezoelectric tranducers were mounted in the sloped and vertical sections of the hopper to monitor peak pressure and pressure rate of rise and record the data on an oscillograph. A minor fabrication error was located in the sloped section of the hopper. It did not affect the structural integrity of this section, but it did interfere with pressure gage mounting. Consequently, a quick-fix remedy to accommodate mounting the transducers apparently affected the response of the transducers at these locations. For this reason, pressure and pressure-versus-time data are not valid and not reported.

Program Change

Because only orderly burning with no tendency toward violent explosive reactions occurred in full-scale prototype hopper tests, program revisions were sought to perform

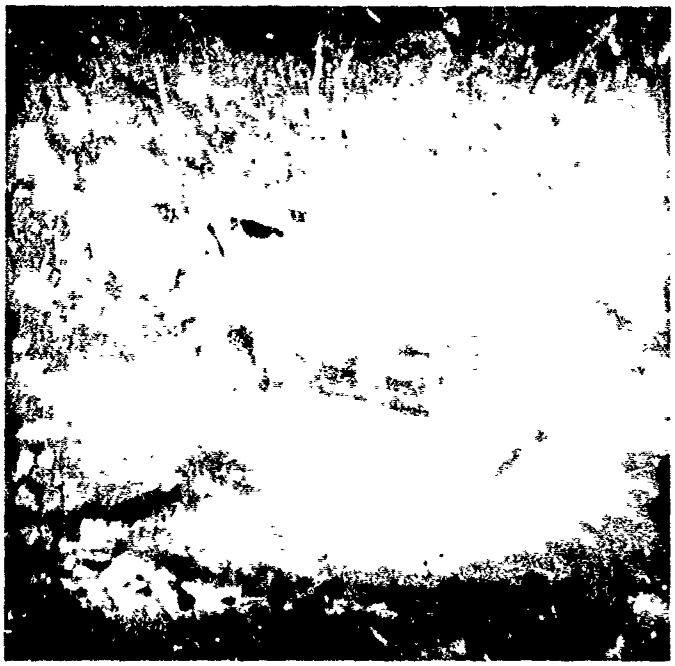
Figure 4
Sequence of Events During Testing

4a
Loaded Hopper Ready for Test

4b
64 Milliseconds after Ignition

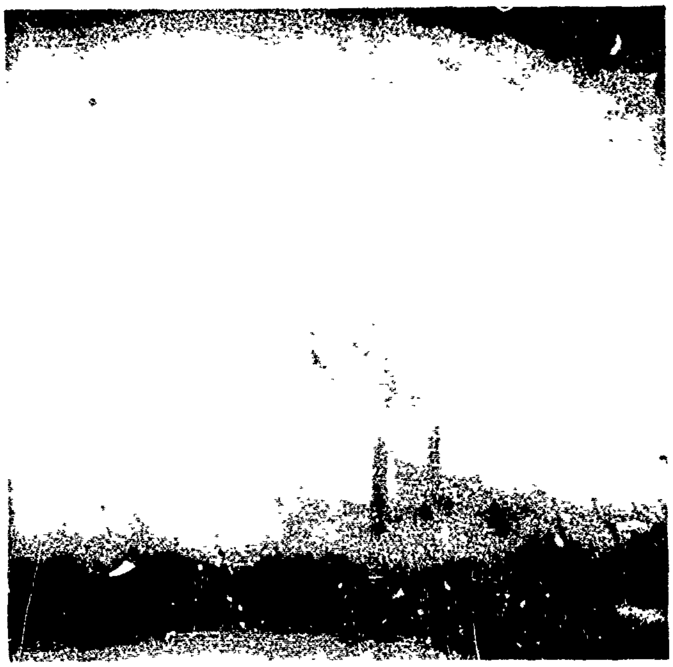
Figure 4 (Con't)

4c
125 Milliseconds after Ignition



4d
225 Milliseconds after Ignition

Figure 4 (Con't)



4e
5 Seconds after Ignition

4f
View showing Height of Fireball

more severe hopper tests involving greater propellant quantities and restricted venting (Ref 2). The requested revision was approved by ARMCOM Safety (Ref 3). However, this additional testing was not conducted because of failure of the Frackville, Pennsylvania, test location to meet the quantity-distance requirement of AMCR-385-100 and DOD 4145.26M for testing 900 pounds of M1SP propellant, and the inability to obtain an alternate remote-test site near Frostburg, Maryland, due to negative public reaction in that area.

A second program study revision (Ref 4) involving expanded critical height-to-explosion tests was not approved because of Picatinny Arsenal personnel's interest in directing remaining project funds to answering in-process hazard classification questions pertaining to the automated multi-base propellant dryer.

Propellant Sensitivity to Flame

Results of standard critical-height tests for M1SP at larger diameters are found in Table 4 and plotted in Figure 5. As can be seen from these data, M1SP propellant transits from burning to an explosive reaction in steel confinement. The propellant explosion height is observed to increase with diameter and exhibits a fairly linear relationship up to the 18-inch test diameter.

The propellant explosion height did not level off or approach a constant value with increasing diameter over the test range studied. Assuming that a constant propellant height will be reached when a state of propellant mass self-confinement (for explosion) exists, present data indicate that the propellant mass self-confinement state is apparently beyond the maximum dimensions tested. The importance of propellant-mass confinement lies in preventing transition from burning to an explosion either by establishing a maximum permissible propellant height or adopting pressure-relief venting of process vessels, if possible.

Extrapolation of critical height to explosion data in Figure 5 for a 36-inch diameter predicts that the propellant should not transit from burning to an explosion up to a M1SP propellant-bed depth of 50 inches. The full capacity of the hopper is approximately 900 pounds of M1SP. This conclusion still requires substantiation in full-scale tests to establish the validity of the small-scale critical height-to-explosion data for predicting propellant explosion heights in processing vessels. Also, the propellant mass self-confinement level for M1SP propellant is undefined.

Table 4

Flame-initiated explosion characteristics for M1SP propellant

Diameter[a] (in.)	Critical height-to-explosion [b] (in.)	Loading density[c] (gm/cc)
1	7	0,61
2	12	0.58
4	13	0.56
6	16	0.60
8	22	–
18	32	–

[a] All tests performed in Schedule 40 black seamless-steel pipe with steel fittings.

[b] Defined as the height above which an explosion can occur when subjected to bottom flame initiation produced by a 12-gram bag igniter (50/50 mixture of FFFG black powder and 2056 casting powder).

[c] Average density experienced during testing.

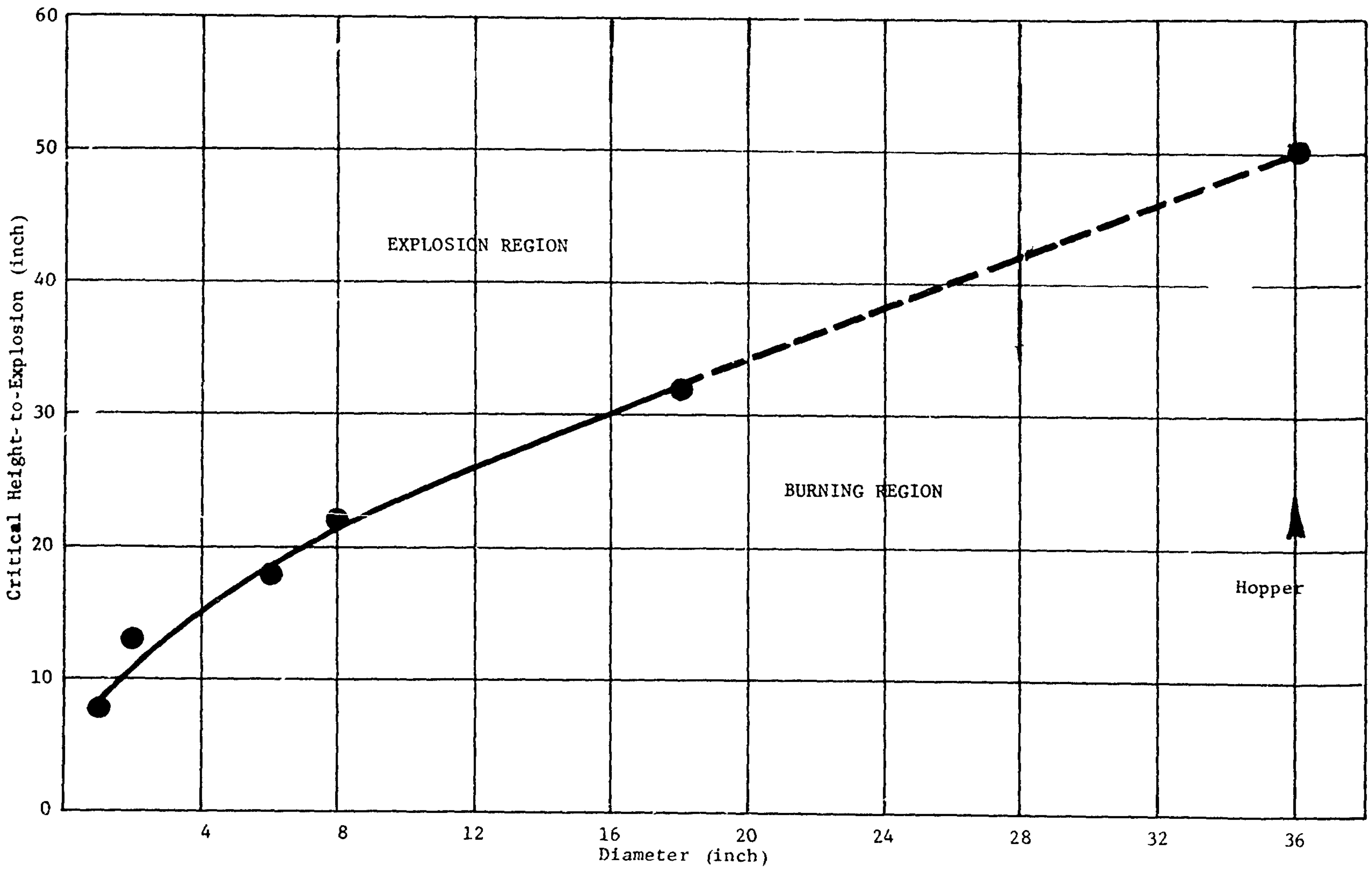


Fig 5 Critical height to explosion as a function of diameter for M1SP propellant

EXPERIMENTAL

Large-Scale Hopper Tests

The large-scale vented-hopper tests were performed at Hercules, Incorporated facilities at Frackville, Pennsylvania. Minor test-site modifications were required and involved grading for access roads and equipment placement at the test area and at the personnel control shelter location, providing additional earth barricading around test hopper, and providing electrical service for instrumentation. A schematic layout of the Frackville test site is shown in Figure 6.

Design criteria for the venter hopper were provided to the Rexnord Company by RAAP personnel. Design changes to accommodate adapting instrumentation, assembly, and working around the hopper were made to the basic hopper design in Figure 2 prior to fabrication. These are listed in Table 5 and depicted in Figure 7.

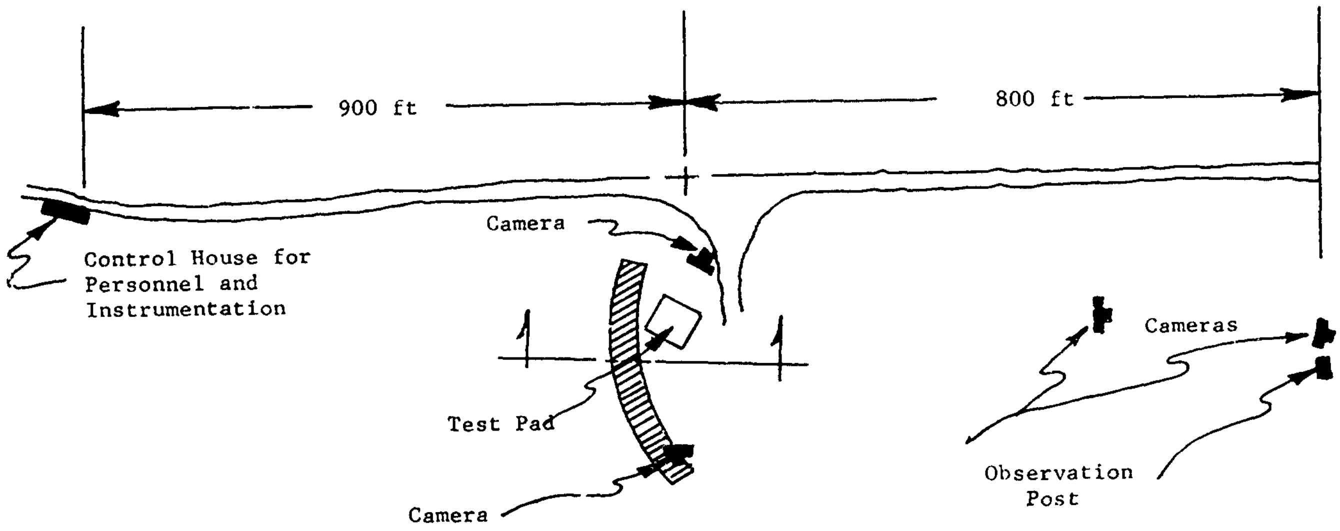
Piezoelectric transducers were mounted at selected points on the hopper's vertical axis for measuring pressure-time responses. Low resistance RG-62U cable transmitted pressure signal information for recording on an oscillograph. Four cameras having framing rate capabilities up to 5,000 frames per second were positioned for adequate hopper coverage from all angles. A site location plan is depicted in Figure 6. Pertinent details listing instrumentation and recording capabilities are found in Table 6.

A 2-ounce bag igniter consisting of FFFG black powder was located 4 inches above the hopper discharge opening. The black powder was initiated with a M100 Atlas Match. The M1SP propellant (20,000 pounds) was shipped from Indiana Army Ammunition Plant, Charlestown, Indiana, to Hercules Incorporated, Frackville, Pennsylvania. Three thousand pounds were delivered to Allegany Ballistics Laboratory for critical height-to-explosion tests at that facility.

A total of 13 hopper tests were conducted. Three trials were performed in the 1/2-inch mild steel hopper with propellant weights of 250, 350, and 450 pounds. Ten confirmatory tests of 450 pounds each were then performed in the 1/4-inch-thick stainless steel prototype hopper. Figure 1 shows the hopper after the ten trials.

Critical Height-to-Explosion

All tests were conducted in Schedule 40 black seamless-steel pipe with steel caps or welded closures. The standard 12-gram bag igniter was employed as the ignition system.



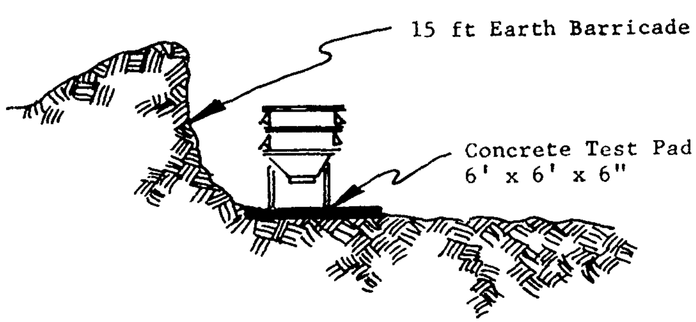


Fig 6 Test site at Frackville

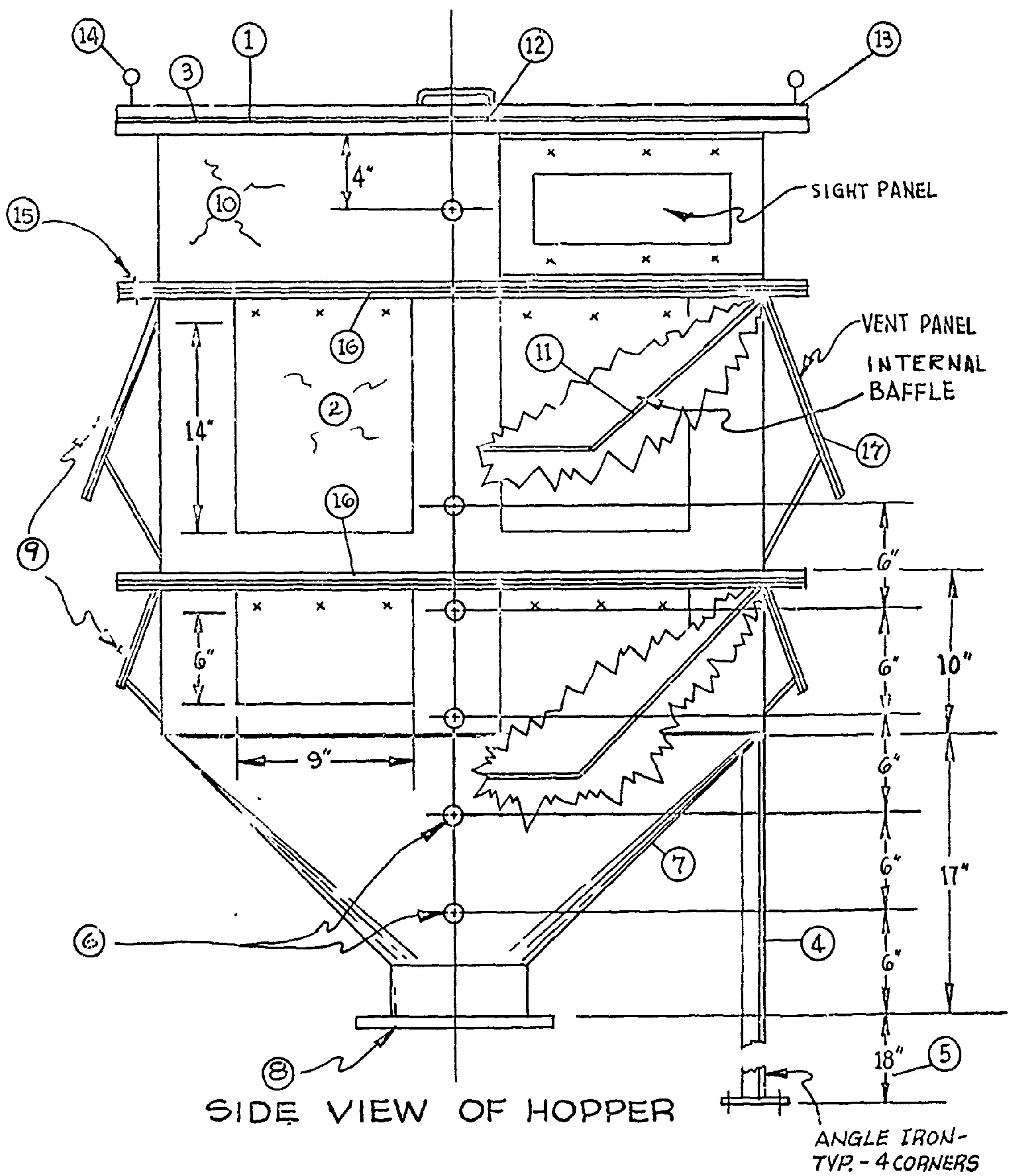


Fig 7 Revisions to basic hopper design (See Table 5)

Table 5

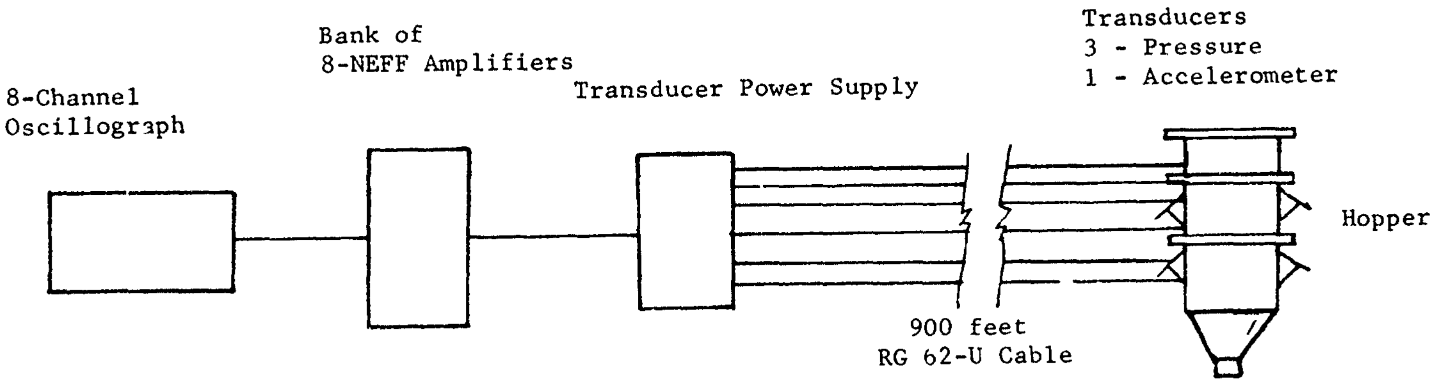
Revisions to basic hopper design*

Revision	Explanation of Change
1	Hopper lids to be 1/8-inch stainless steel.
2	Vent area increased from 54 in^2 to approximately 84 in^2.
3	No fire nozzles to be installed.
4	Hoppers to have four supporting angle-iron legs with plates for anchoring to test pad.
5	Hopper discharge outlet to be 18 inches from test pad when secured to test pad.
6	Six standard 1-inch NF taps for pressure transducers. Blank plugs to be provided.
7	Provision for additional blow-out panels included (four sides) in the event Test Plans B and C are performed.
8	Deleted
9	Stainless steel plates drilled and tapped to mount two accelerometers.
10	Carbon steel hoppers to have primer coat only--no paint.
11	Welds to be full penetration--no x-ray or dye penetrant inspection required.
12	Top inlet-port vertical extension omitted--8-inch diameter hole in center of lid only.
13	Lid to have four 1" x 1" x 1/4" angle irons welded from center hole to increase rigidity of lid.
14	Lid to have eye bolts at each corner to accommodate retrieval of lid after separation from hopper during testing.
15	Bolts instead of clamps to be used to secure sections together.
16	Neoprene hinge.
17	Neoprene.

* Refer to Figure 7.

Table 6

Schematic and particulars for instrumentation and circuitry



Parameter	Transducer	Amplifier	Cable	Recording
Pressure	3-PCB-101A04	NEFF 109-6	900 ft. RG 62U 62U	CEC-5-124A
Acceleration	PCB- PCB-	NEFF	900 ft. RG 62U	Cameras CEC-5-124A
Reaction Times of Vents and Lid	--	--	--	Cameras 1-1000 ft/sec 1-500 ft/sec 2-64 ft/sec
Burning Time				Cameras

The test vehicle was charged to the top with M1SP propellant to a loading density of 0.56 to 0.61 gram/cm^3. The top open end was taped closed to prevent propellant spillage. For most tests, a constant resistance velocity probe was used; however, electrical or mechanical failure of the resistance probe velocity-monitoring system occurred frequently. In addition to probe failure, several velocities were inconsistent with observed pipe damage. For this reason, pipe damage alone was used as the criterion for explosion. An "explosion" was based on a ruptured or a fragmented test vehicle and a "no explosion" based on no test container damage. This relative assessment technique fails to identify detonation, but is sufficiently adequate to identify explosions.

All critical height-to-explosion tests were conducted in accordance with Hercules Incorporated procedure HD-SG-3906. All 18-inch-diameter tests and several eight-inch-diameter tests were performed at the Hercules, Incorporated, Allegany Ballistics Laboratory test facility.

CONCLUSIONS

Full-scale hopper tests have confirmed a Class 2 propellant burning hazard for 450 pounds of M1SP propellant in the ASBL vented air-dry module discharge hoppers. The hopper-pressure-relief venting design functioned as intended and will preclude M1SP propellant transiting from slow burning to an explosive reaction if initiated.

Ten large-scale tests have been performed in the stainless steel prototype hopper depicted in Figure 1. Only orderly burning with no tendency toward violent reactions occurred. High-speed photographic coverage together with visual examination revealed the hopper and neoprene vent panels sustained no noticeable damage such as warping or flame erosion. A propellant surface-to-hopper vent area ratio of $\approx$660 was established for venting reaction gases to prevent transition from burning to an explosion for 450 pounds of M1SP propellant.

Flame-initiated critical height-to-explosion testing confirmed that M1SP readily transits from burning to an explosive reaction. The propellant explosion height was found to be a function of test-vessel diameter. Extrapolation of the projected critical height-to-explosion data predicts that no explosive reaction should occur in the ASBL vented air-dry module discharge hopper for propellant depths up to 50 inches. This conclusion requires substantiation in full-scale tests to establish the validity of the small-scale critical height-to-explosion data for assessing the explosion probability for explosives and propellant in processing vessels.

RECOMMENDATIONS

1. The specially designed hopper depicted in Figure 1 and Drawing No. 3-45867 should be adopted for use in ASBL air-dry finishing operations to eliminate a Class 7 explosive hazard.

2. M1SP propellant manufacturing, storage, and loading operations at other Army installations should be hazard reviewed in light of current findings Where practical, M1SP propellant heights in processing and storage vessels should be maintained below the 32-inch nonexplosive height established in large-scale critical height-to-explosion tests. Also, pressure-relief venting should be incorporated in the design of processing and storage vessels to have at least a 668:1 propellant surface-to-vessel vent area ratio to minimize the chance for explosive reactions.

3. Critical height-to-explosion testing should be continued with particular emphasis on performing tests in vessel diameters larger than 18 inches for the purpose of (1) investigating the propellant mass self-confinement effect on the explosive material height for M1SP propellant, and (2) validating the use of a relatively inexpensive critical height-to-explosion test to predict the explosion probability for propellants in manufacturing operations.

4. Studies should be performed to assess the feasibility for adapting pressure-relief venting concepts in multi-base propellant manufacturing equipment to reduce existing Class 7 explosive-hazard operations to Class 2 burning hazards.

5. Large-scale hopper testing should be continued and expanded to establish minimum pressure-relief venting requirements for precluding flame-initiated explosive reactions for M1SP propellant quantities up to the maximum hopper capacity of 900 pounds.

6. Implement Production Engineering Project PE-565, entitled "Determination of an Explosion Probability Model." This project proposes to investigate relevant variables influencing critical height-to-explosion and to provide engineering design criteria for preventing explosive reactions in processing equipment. A mathematical model will correlate and express explosive probabilities in terms of the propellant's chemical, physical, and confinement parameters.

7. Studies and tests should be performed to demonstrate effective safe guards for containing fireballs accompanying burning of large quantities of propellant. For CASBL applications, the combination of screen vent covers for propellant containment in a vessel and radiation sensor/deluge systems for quick detection and

quenching should be explored as means to minimize possible major equipment and facility damage in the event of a fire in single-base finishing operations.

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